The Coefficient of the Rate of Absorption in Horizontal Mechanical Scrubbers with a Low Number of Revolutions

Zhurnal Prikladnoy Khimii, Vol XXIV, No 4, 1951,
pp 341-352; L. I. Agarev (Moscow-Leningrad)
Per Ab 182T39

THE COEFFICIENT OF THE RATE OF ABSORPTION IN HORIZONTAL MECHANICAL SCRUBBERS WITH A LOW NUMBER OF REVOLUTIONS

L. I. Azarev

Published data on the industrial use of absorption equipment with automatic regeneration of the contact material are extremely limited. There are descriptions of various designs of mechanical scrubbers, but the quantitative characteristics of their operation are lacking.

The aim of this investigation was to obtain a knowledge of values of the coefficient of the rate of absorption on large-scale laboratory models of a horizontal mechanical scrubber. The magnitude of the coefficients of absorption was determined as a function of the number of revolutions of the shaft, the rate of passage of the gas, and the rate of flow of the liquid. Basic experiments to clarify the effect of these factors were carried out on the absorption of carbon dioxide, a gas with low solubility, by water, and only a few experiments were conducted on the absorption of ammonia, a gas with high solubility, by water.

The data on the coefficients of absorption obtained on the model were compared with the coefficients found in the same manner on an apparatus of another design. On the basis of this work, conclusions were drawn on the use of as absorption apparatus of mechanical scrubbers with a horizontal axis of ratation.

In most absorption apparatus (bubble columns, spray columns, and filled towers) mutual intermixing and development of a surface of contact between the liquid and the gaseous phase are accomplished by means of special stationary devices for the distribution and movement of the two phases in the apparatus.

In mechanical scrubbers the regeneration of the contact material is carried out by the intermixing of the liquid and the gas by means of a rotating mechanical device.

The mechanical scrubbers described in literature can be divided into two groups:

1) Scrubbers with a vertically rotating shaft, among them the Field scrubber, the centrifugal MacLaurin[1] [?] scrubber, and others;

2) Scrubbers with a horizontally rotating shaft, such as the scrubbers with reticular disks[2], "Standard" scrubbers[1], etc.

All vertical mechanical scrubbers, and also some horizontal ones, run at 100 and more rpm. A spraying device of some kind (fans, disks, bundles of rods, etc.) is fastened to the shaft and sprays the liquid into the gas stream. In this manner, an extremely intensive development of surface absorption will take place, determining the effective work of the apparatus. The conditions of gas absorption in these scrubbers come closest to those prevailing in hollow absorption towers with liquid spray.

The mechanical scrubber with a horizontally rotating shaft[2] operates on a different principle. In this case, the shaft rotates relatively slowly. The reticulated or latticed disks, at every revolution, entrain liquid from the lower part and raise it in the form of a thin film into the upper zone, where it is saturated by the gas to be absorbed. Then, upon immersion in the bulk of the liquid, this liquid is regenerated, again emerges into the gas, and so forth.

Here the conditions of the absorption process are very close to those prevailing in the filled scrubbers, only instead of the liquid film running off over the filling material, the films are moved by rotating disks.

In the literature, as we have stated, there are no numerical data characterizing the efficiency of operation of the above-mentioned mechanical absorption devices. If general considerations are used for orientation and if a description is available; the following conclusion can be made: the resistance to the passage of gas should be negligible; absorption of the gas ought to be accomplished by a minimum quantity of absorbent; the constant regeneration of the liquid film should afford high efficiency in the absorption of gases with low solubility. The horizontal scrubber is basically suited for performing of absorption operations in which the liquid is contaminated by a sediment or even in cases where formation of a sediment takes place in the course of the absorption process as a result of reactions which take place.

The chief deficiency of the mechanical scrubbers is the additional power required for turning the shaft. This power consumption is especially high in scrubbers with high rpm, and makes them uneconomical in the first place. For this reason, a horizontal scrubber with low rpm was used in our experiments.

Experimental Part

The experimental model of the mechanical scrubber, in dimensions and output, corresponded to the scale of a semi-plant laboratory installation (Fig 1).

The casing of the scrubber model measured 150 mm in diameter and 400 mm in length. It consisted of two parts in the form of semicylinders. The lower part, or vat, for assuring effective circulation of the absorbing liquid, was divided into 4 sections by partitions. The upper part, or cover, was made of plexiglass. This permitted observation of all phenomena taking place inside the apparatus during the experiments. The junction between the upper and the lower semicylindrical parts was equipped with a hydraulic seal to keep the apparatus airtight.

Six outlets were soldered to the underside of the vat. They served as intakes and drains for the absorbent and also for drawing samples and draining the sections. A shaft ran through the axis of the cover. The disks were attached to it. They were made of sheet iron 0.5 mm thick. Sixty openings were drilled, uniformly distributed over the entire surface of the disks. Their diameter was 10 mm, and the centers were 15 mm apart (Fig 2). A preliminary test of the disks with openings of a smaller diameter (4, 6, and 8 mm) showed that in emerging from the liquid the openings were partially closed by a liquid film, which prevented the passage of the gas through the cross-section of the scrubber. However, openings with 10 mm diameter were no longer closed by a film, and for that reason, we used that dimension for the disks of our experimental model. The disks had a diameter of 150 mm. The clearance between the edges of the disks and the surface of the case did not exceed 1.0 to 1.5 mm. In distributing the disks along the shaft, the distance between them was kept at 20 mm.

Before the disks were installed, they were carefully cleaned of grease, so that their surface could be completely wetted. The number of rpm of the shaft could be varied from 2 to 55.

A complete sketch of the experimental installation is shown in Figure 1. In this arrangement, the air for forming the gas mixture is supplied by a blower. The gas to be absorbed (carbon dioxide or ammonia) enters from the cylinder (1), passes through a reducing valve and then through a trap (2). The quantity of air and gas which enters is measured by means of a flowmeter (5). To safeguard continuous delivery of gas from the cylinder during the experiment, a liquid-filled pressure regulator (3) is connected in front of the flowmeter. The static pressure of the gases is measured by a U-tube pressure gauge (4). Behind the rheometer, the gas pipes are joined into one common line through which the gas-air mixture enters the scrubber (6). On the wall opposite the gas intake there was a nozzle with a hose for the exhaust of the gas from the scrubber. Pipes from the aspirators (7) were connected to the intake and exhaust hoses. The gas taken away by the aspirators during the experiment was analyzed to determine the content of the component to be absorbed.

Water functioning as the absorbent entered from the tapwater line into a pressure flask in which the water level was kept constant. From the flask it flowed through a flowmeter (9) at a definite rate and entered the first section of the vat of the scrubber. The flow of the water through the sections was in opposite direction to the gas flow. From the fourth and last section the water (solution) flowed out into a measuring tank where it was measured at the conclusion of the experiment. Samples of the aqueous solution leaving the scrubber were periodically drawn into flasks during the experiment.

A constant water level was maintained inside the scrubber by means of an overflow drain. In the experiments with carbon dioxide the height of the drain was 62 mm. The volume of liquid inside the scrubber was 3.5 liters. In the experiments with ammonia, where the absorption took place only in one section, the height of the drain was reduced to 50 mm, and the volume of liquid to 0.7 liters.

The experiments were performed under conditions of a continuous process. They provided for a constant rate of flow of gas and liquid through the apparatus, constant temperature of gas and liquid, and a constant number of rpm of the disks. The gas temperature was maintained at 16 to 17°C. Constant conditions were also maintained in the analysis of the samples of liquid withdrawn from the scrubber. The composition of the liquid changed hardly at all during the experiment. As a matter of fact, as shown by the data of table 1, the concentration of the gas being absorbed inthe aqueous solution leaving the scrubber increases at the start of every experiment and then, having reached a definite level corresponding to the conditions of the experiment, remains unchanged. This constancy of the concentration set in within 5 to 8 minutes from the beginning of the experiment, depending on the rate of flow of the water and gas intake. The quantity of water passing through the scrubber in the experiment was 0.5 to 2.0 liters per minute. The quantity of gas drawn through the ~~The resistance to the passage of the gas in-~~

apparatus varied from 5 to 24 liters per minute. The resistance to the passage of the gas in the scrubber varied between 3 and 25 mm of water column. The experiments lasted from 15 to 20 minutes. Samples of the outflowing water were taken every $2\frac{1}{2}$ minutes. Up to 8 samples were taken during one experiment. In some cases, two parallel samples were taken, and sometimes samples were taken from the outlet nozzles of the first and fourth sections.

It is seen from the numerical data of Table 1 that the concentration of carbon dioxide in the water taken from the bottom of the last section is somewhat lower than at the overflow drain. The increased concentration in the upper layer of the water may be explained by additional absorption of gas at the water surface. The agitation of the liquid caused by the disks, even at 52 rpm, does not suffice for complete equalization of concentration throughout the height of the liquid.

Determination of carbon dioxide in the water was carried out according to a method described in literature[3]. The carbon dioxide content in the tap water supplied to the scrubber was determined several times while the experiments were being carried out. It was only 0.005 grams per liter. Thus, in the determination of the carbon dioxide which had been absorbed, this quantity was of no importance and could therefore be completely neglected.

Samples of the intake and exhaust gas were taken continuously during the experiment by aspriators with a capacity of 2 liters each. The analysis of these samples for their carbon dioxide content was carried out with an Orsat apparatus.

For determination of ammonia in the outflowing water, samples are taken up in a measured quantity of a titrated sulfuric acid solution with back titration of the excess acid by sodium hydroxide in presence of a mixture of methyl red and methylene blue indicators. For determination of the ammonia in the gas during the taking of the sample, traps (11) containing a titrated sulfuric acid solution are placed in front of the aspriator. They absorb the ammonia from the gas being sampled. The titration of the excess acid in the traps after the experiment is carried out exactly in the same manner as the analysis of the aqueous solution.

Discussion of the Results

The solubility of carbon dioxide in water is very slight. Thus, for instance, at 10°C, Henry's Constant equals $0.791 \cdot 10^6$ mm/molecular fraction. Calculating, according to this, the equilibrium concentration for a gas with 10 percent carbon dioxide, we find that it corresponds to 0.24 grams per liter. As a consequence of this, lowering of the carbon dioxide concentration in the gas during its passage through the apparatus did not exceed 0.2 to 0.4 percent by volume at an over-all concentration of about 10 percent carbon dioxide. The situation is different as regards the change of the carbon dioxide concentration in the liquid phase. While the tap water supplied to the scrubber contained 0.005 grams of carbon dioxide per liter, the concentration in the outflowing water rose to 0.1 to 0.2 grams per liter, i.e., increased by several tens of times.

In the analysis of the intake and exhaust gas, an average for the experiment was taken. At the same time, 6-8 tests were made for the analysis of the liquid phase. The quantity of the flowing water was determined, in addition to the use of a flowmeter, by direct measurement of the water after the experiment, which precluded the possibility of errors in the experiments.

In view of all this, it will be more convenient and more exact to calculate the quantity of absorbed carbon dioxide from data on the liquid phase.

Since in the absorption of carbon dioxide by water the basic resistance is represented by the liquid phase, the moving force can most conveniently be expressed here as differences between concentrations of the gas in the liquid.

The calculation of the general coefficient of absorption is therefore derived by means of the equation

$$K_L = \frac{W}{F \cdot \theta \cdot \Delta C} \quad \frac{kg}{m^2 \cdot hrs \cdot kg/m^3} \qquad (1)$$

where W is the quantity of absorbed substance throughout the experiment (in kilograms), F is the absorption surface (in square meters), is the time of absorption (in hours), C is the mean logarithmic difference of concentrations of the absorbed component (in grams/liter) or in kilograms/cubic meter, which gives the same result). The quantity of carbon dioxide, absorbed within 1 minute, is computed by the equation

$$W_{min} = \frac{L}{1000} (C_k - C_n) \text{ kilograms/minute} \qquad (2)$$

where L is the quantity of water flowing through (in liters/minute); C_k the concentration of carbon dioxide in the water flowing out (in grams/liter), C_n the concentration of carbon dioxide in the water flowing in (in grams/liter), which is always equal to 0.005.

In gases of counter-current of gas and liquid, the mean difference of concentration is expressed by the equation

$$\triangle C = \frac{(C_{rn} - C_n) - (C_{rk} - C_k)}{2.3 \lg \frac{C_{rn} - C_n}{C_{rk} - C_k}} \qquad (3)$$

where C_{rn} and C_{rk} are the equilibrium concentrations upon entrance into the apparatus and upon leaving the apparatus. The absorption surface F was arbitrarily taken as the surface of the disks minus the area of the openings and of the part of the surface of the disks which was immersed in the liquid. With 20 disks, the surface was 0.312 m^2. (The surface of the water in the scrubber, amounting to 15 percent of the working surface of the disks, was not used in the calculation).

Equation (1) thus becomes the following expression:

$$K_L = \frac{W_{min} \cdot 60}{\Delta C \cdot 0.312 \cdot 1000} = 0.192 \frac{min}{\Delta C} \left(\frac{kg}{m^2 \cdot hrs \cdot kg/m^3} \right)$$

The value of the absorption coefficient, expressed in partial pressures, i.e., K_G, in the case of absorption of carbon dioxide by water is found from the relation $K_G = K_L/\psi$, where ψ is the Henry coefficient reduced to the dimension mm $Hg/(kg/m^3)$.

Ammonia is easily soluble in water. Consequently, in its absorption the basic resistance is the gas film. Therefore, it is more convenient in this case to calculate the coefficient of the rate of absorption by means of the expression of the moving force in partial pressures of the gas being absorbed. For this purpose, we use the equation

$$K_G = \frac{W}{F \cdot \tau \cdot \Delta P} \quad \frac{kg}{m^2 \cdot hrs \cdot mm\ Hg} \tag{4}$$

where ΔP is the mean logarithmic difference of partial pressures of ammonia at the intake and the outlet of the apparatus. The other designations are the same as above. It should be pointed out that, in our experiments, the water supplied to the absorber did not contain ammonia, and that its concentration in the outlfowing water did not exceed 1.25 to 2.25 grams per liter. At these concentrations and an air temperature of 16 to 17°C the equilibrium partial pressure of ammonia approximates zero and cannot be taken into account. Therefore the moving force of absorption can be expressed as the mean logarithm of partial pressures of ammonia in the gas upon entry and on leaving the apparatus, according to the equation:

$$P = \frac{P_n - P_k}{2.3 \lg(P_n/P_k)} \qquad (5)$$

where P_n and P_k are the partial pressures of ammonia in the incoming and the outgoing gas.

In the experiments with ammonia, the absorbing surface was reduced considerable. Preliminary examination showed that not only with 20 disks, but also with 10 disks, there is full absorption of ammonia in the scrubber, so that none was detected in the outgoing gas. In view of this fact, the experiments were conducted with only 4 disks. In order to reduce the water surface, we passed the water only through one section where 4 disks were revolving. The depth of immersion was less, and the surface of absorption in this case was 0.08 square meters.

The quantity of ammonia absorbed can be calculated on the basis of the gas and on the basis of the liquid. As can be seen from Table 3, the difference is quite negligible. However, considering the greater accuracy of the data obtained by analysis of the liquid phase, the quantity of absorbed ammonia was estimated on the basis of analysis of the aqueous solution, i.e.,

$$W_{min} = LC_k \text{ grams/minute}$$

where L is the quantity of water flowing through the scrubber (in grams per minute); C_k is the concentration of ammonia in the water at the outlet (in grams per liter or, which is the same thing, in kilograms per cubic meter.)

The entire equation for K_G IS EXPRESSed as follows:

$$K_G = \frac{Ck \cdot 60}{0.08 \cdot \Delta P \cdot 1000} = 0.75 \frac{LCk}{\Delta P} \quad kg/m^2 \cdot hrs \cdot mm\ Hg$$

The basic data obtained from the experiments on the absorption of carbon dioxide and of ammonia by water in a mechanical scrubber and the absorption coefficients calculated for them are given in Tables 2 and 3.

The coefficients of the rate of absorption, presented in Table 2, are expressed by values of K_L in the range of 0.07 to 0.25 $kg/m^2 \cdot hrs \cdot kg/m^3$, which translated into the coefficient of absorption K_G related to the gas phase corresponds to 0.000217 - 0.000654 $kg/m^2 \cdot hrs \cdot mm\ Hg$.

For the purpose of comparison, we cite the values of K_L for carbon dioxide in the same units, as obtained by other authors under the same conditions of absorption.

In Perry's handbook[4] the following data are given for the absorption of carbon dioxide:

1) Gas passed over the surface of agitated water; K_L 0.076

2) Absorption from bubbles of pure carbon dioxide in a stream of down-flowing water; temperature 25°C; $K_L = 0.914$

3) Absorption by drops of water falling from a height of 50 cm into an atmosphere of pure carbon dioxide: $K_L = 2.60$

4) Absorption from a mixture of carbon dioxide and air, water agitated by a stirrer, gas not agitated, temperature 26°C:

Percent carbon dioxide by volume	100	50	25
K_L	0.098	0.088	0.079

In the work of Prof Shabalin[5] the following data are listed for the coefficient of absorption of carbon dioxide in water. In absorption by drops of a diameter above 1 mm, $K_L = 1.0$. The K_L in absorption from rising bubbles is the same. In absorption by a down-flowing film of water, with various intensities of spraying, K_L is reduced to 0.3 - 0.8.

These data indicate that the absorption coefficients obtained in the mechanical scrubber are 4 to 5 times lower than those obtained by bubbling or by falling drops. They are greater than those obtained in absorption by agitated liquids from a non-moving or slowly moving gas.

The absorption coefficients found by us are very close to those obtained in absorption of gas by a flowing film of liquid (with small densities of spray). This closeness, obviously, is explained by the similarity, as pointed out above, between the hydraulic conditions of the absorption process in mechanical and in filled scrubbers.

The rate of drainage of the liquid through the filling, as the average throughout the thickness of the layer of down-flowing liquid, can be expressed by the formula:

$$V = Q/(\gamma \cdot \delta \cdot S)$$

where Q is the quantity of liquid (in grams per second), γ the thickness of the layer (in cm), δ the specific gravity (in grams per square centimeter) and S the wetted perimeter of the filling (in cm).

For Raschig rings of 50 x 50 x 5 mm, with a spraying density of 30 cubic meters per square meter · hr, the thickness of the film is 0.035 cm [6]; the wetted perimeter for those rings, numerically equal to the specific area of the filling, is 87.5 m.

By substituting the given data in the above formula and converting centimeters into meters, we obtain for the rate of drainage:

$$V = \frac{30}{3600 \cdot 0.00035 \cdot 87.5} = 0.273 \text{ m/sec}$$

The rate of drainage of water through the tubes of sprinkler coolers is 0.15 to 0.3 m/sec [2], i.e., of the same order of magnitude as that calculated for fillings.

In our scrubber, the peripheral speed, at different rpm of the disks, was as follows:

rpm	17	35	52
Speed for points at edge of disk (m/sec)	0.13	0.27	0.40
Speed for mean circumference (m/sec)	0.07	0.14	0.20

Thus, under the conditions of our experiments, the magnitude of the speed of displacement of the liquid by means of the disks is of the same order as the rate of drainage of the liquid through filled scrubbers and consequently brings about no radical change in the motion of the down-flowing layer; this also explains the close similarity between the coefficients of absorption of the two cases compared here.

It is also evident from Table 2 and from Illustration 3 that the rpm of the disks exerts a decisive influence on the magnitude of K_L. Thus, if the number of rpm is doubled, K_L increases 1.75 to 2 times. This increase is analogous to the increase of K_L in filled scrubbers in which the density of the spray is increased, i.e., where the rate of down-flow of the liquid film is increased.

Increased supply of liquid to the scrubber slightly raised the value of K_L. For instance, if the rate of inflow of water was increased from 0.5 to 1.0 liters per minute, i.e., if it was doubled, K_L increased from 0.14 to 0.17 at 36 rpm and from 0.195 to 0.245 at 52 rpm, i.e., it increased 1.2 and 1.26 times.

Change in the rate of flow of the gas does not have any noticeable effect on the magnitude of K_L. It is quite evident from Figure 4, that if the volumetric rate of flow of the gas is increased ffom 5 to 23.6 liters per minute, while the rpm are unchanged and the supply of water remains constant, the value of K_L remains constant. It should be noted that the linear speed of the gas, related to the lateral cross-section of the scrubber, gas volume, was very insignificant in this case, being ~~in~~ the range of 0.008 to 0.038 m/sec. It is obvious that this gas speed could not cause turbulence by friction in the liquid film, which plays a predominant role in the absorption of carbon dioxide.

Several experiments, as mentioned, were carried out on the absorption of ammonia by water. The experimentswere performed under the following conditions: 35 rpm, water supply 1.0 liters per minute, rate of gas flow varied from 10 to 20 liters per minute. As Table 3 shows, the magnitude of the coefficient of absorption was within the range of 0.015 to 0.023 kg/m^2 • hrs • mm Hg. An increase in the rate of gas flow from 10 to 20 liters per minute, i.e., doubling of it, brought about an increase of K_G from 0.017 to 0.023 on the average, i.e., it increased 1.35 times. In this case, the effect of the rate of gas flow is already noticeable, while it was not observed in the absorption of carbon dioxide. However, this increase is less than under the conditions of a sprayed filling, where an increase of K_G is proportional to the increase of the rate of gas flow in the power, 0.8, which in the given case would amount to an increase of K_G by the factor of 1.74.

In Perry's handbook[4] a series of values of K_G for the absorption of ammonia by water is given. The data were obtained under various conditions of the process. The numerical data are given in the dimension mol/m^2 • hrs • atm. They were converted to the dimension of K_G which ~~wex~~ used (kg/m^2 • hrs • mm Hg). For towers with sprayed walls, with a change of the rate of gas flow from 0.48 to 0.015 m/sec, the value of K_G at 10°C changed from 0.0383 to 0.0383 to 0.00224, and at 30°C and the same rates of flow, correspondingly, from 0.0338 to 0.00224.

In work with a column with sprayed walls, 5 cm in diameter and 81 cm high, at a temperature of 10°C and the rate of gas flow reduced from 0.259 to 0.049 kg/sec · m^2

of cross-section area of the column (0.32 to 0.05 m/sec), the value of K_G changed from 0.0203 to 0.0053 kg/m^2 • hrs • mm Hg.

In the work of Prof Shabalin[5], which has already been mentioned, the following values are given for the coefficient of absorption of ammonia by water: in absorption by drops of a diameter above 1 mm, K_G equals 0.3 to 0.35 kg/m^2 • hrs • • mm Hg. It has the same order of magnitude in absorption from rising bubbles. K_G for a down-flowing film is within the range of 0.01 to 0.04 kg/m^2 • hrs • mm Hg, i.e., 10 to 20 times less than for drops or bubbles.

From the comparison of the values of K_G obtained in our experiments and in the experiments of other researchers, it is evident that the magnitude of the coefficient of absorption of an easily-soluble gas in the mechanical scrubber is of the same order of magnitude as that in the case of a down-flowing film. Never the-less, considering the low rate of flow of the gas in our experiments, as compared to the rates of flow used by the cited authors, it can be assumed that the K_G in the mechanical scrubber, under favorable conditions, will be somewhat higher than in the case of films draining through a filling.

Conclusions:

1. Values of the coefficients of the rate of absorption by water in mechanical scrubbers with low rpm, both for an easily-soluble gas (ammonia) and a gas with low solubility (carbon dioxide) is close to those of filled scrubbers and considerably lower than those obtained by bubbling or in towers with a liquid spray.

2. Comparing the advantages of the mechanical scrubber of the type described (viz. low consumption of absorbent liquid, possibility of obtaining highly concentrated solutions, lower ing of the resistance to passage of the gas, etc.) and its shortcomings (viz. power consumption for turning the shaft, high wear in an aggressive medium, etc.) with those of the filled scrubber, it must be stated that its use is not particularly effective as compared to the latter.

3. The use of mechanical scrubbers of the type investigated can be justified only when the absorbent liquid is contaminated by sediment or where sediment forms in the course of the absorption of the gas, i.e., where the absorption of the gas is actually carried out by a suspension rather than a liquid. In this case the use of other types of absorbers is made difficult by the possibility of the apparatus getting clogged, while there is no danger of this in the case of mechanical scrubbers.

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/Tables and figures are appended./

Table 1.

Concentration of Absorbed Gases in Water When Leaving Scrubber, According to

Analysis of Several Samples Drawn During the Experiment,

In Grams per Liter

Sample Number	rpm	Rate of Flow of water (1/min)	Rate of flow of gas (1/min)	Concentration of absorbed gases in water upon having scrubber, in g/1 — Time of taking of sample, in min. from start of experiment: 2.5	5	7.5	10	12.5	15	17.5	20	Avg. conc'n of gas in water (g/1)	Conc'n of gas in samples from bottom of 4th section of scrubber, (g/1)	gas being absorbed
1	52	0.5	10	—	0.200	—	0.205	—	0.203	—	0.201	0.202	0.190 and 0.193	CO_2
2	52	0.5	10	—	—	0.204	0.204	0.200	0.198	0.183	0.218	0.201	—	"
6	52	1.0	10	0.181	0.184	0.171	0.179	—	—	0.191	0.189	0.182	—	"
10	35	0.5	10	—	0.197	0.190	0.194	—	0.191	0.188	0.180	0.190	0.181 and 0.182	"
18	35	1.0	10	0.136	0.141	0.138	0.140	0.142	0.131	—	0.137	0.138	0.138	"
29	17	0.5	10	0.146	0.136	0.134	0.135	0.145	0.143	0.137	0.127	0.138	—	"
26	17	1.0	10	0.094	0.103	—	0.096	—	0.105	—	0.095	0.099	0.080 and 0.080	"
4	35	0.5	10	1.25	1.25	1.25	1.22	1.19	1.27	1.26	1.29	1.25	—	NH_3
6	35	0.5	20	2.26	—	2.19	2.21	2.20	2.20	2.20	2.21	2.21	—	"

SECRET

Table 2.

Absorption of CO_2 by Water

No. of Experiment	rpm	Gas						Water					
		Temperature °C	Total volume liters/min	Concentration of CO_2		Quantity of absorbed CO_2 (liters/min)		Temperature °C	Conc'n of CO_2, in grams/liter			K_L $kg/m^2 \cdot hrs \cdot kg/m^3$	$K_g \cdot 10^3$ $kg/m^2 \cdot hrs \cdot mm\ Hg$
				in-coming at inlet	out-going at outlet	by flow-meter	by direct measure-ment		at outlet	Equilibrium at in-let	Equilibrium at out-let		
1	52	16	10	9.2	8.8	0.5	0.5	9	0.202	0.220	0.230	0.203	0.652
2	52	16	10	9.4	9.2	0.5	0.493	9.5	0.201	0.225	0.230	0.198	0.623
3	52	16	15	10.2	10.0	0.5	0.493	10	0.210	0.240	0.245	0.185	0.573
4	52	15	20	10.4	10.2	0.5	0.487	9	0.223	0.250	0.255	0.194	0.622
5	52	16	9.9	9.6	9.0	1.0	0.97	7.5	0.177	0.235	0.250	0.234	0.792
6	52	17	10	9.6	9.1	1.0	0.98	8.0	0.182	0.235	0.245	0.257	0.854
7	52	17	20	10.0	9.8	1.0	0.99	9.8	0.180	0.246	0.250	0.241	0.785
8	52	17.5	20	10.4	9.8	1.0	0.993	10.0	0.184	0.24	0.255	0.246	0.773
9	35	16	9.65	9.3	9.8	0.5	0.494	12	0.132	0.200	0.215	0.124	0.360
10	35	17	8.82	11.1	10.7	0.5	0.453	12.5	0.190	0.235	0.245	0.131	0.373
11	35	17	10	11.8	1.06	0.5	0.503	11.5	0.192	0.245	0.255	0.136	0.400
12	35	16	20	10.3	10	0.5	0.497	10	0.196	0.240	0.245	0.153	0.474
13	30	17	20	10	10	0.5	0.508	9.5	0.181	0.243	0.243	0.147	0.463
14	38	16.5	5	11.4	10.2	1.0	1.12	7.5	0.162	0.265	0.295	0.178	0.602
15	38	15.5	5	10.8	9.8	1.0	1.09	7.5	0.158	0.255	0.280	0.178	0.602
16	35	17	10	9.6	9.1	1.0	1.116	9.0	0.140	0.225	0.238	0.191	0.613
17	35	16	10	10.6	10.0	1.0	1.04	8.0	0.147	0.255	0.270	0.158	0.526 — 0.518
18	35	16.5	10	9.4	8.9	1.0	1.07	8.0	0.138	0.23	0.245	0.171	0.638
19	38	17	15	9.8	9.4	1.0	1.083	8.0	0.152	0.245	0.252	0.192	0.557
20	38	17	15	10.0	9.6	1.0	1.085	9—8	0.145	0.240	0.255	0.177	0.542
21	35	17	20	10.2	10	1.0	1.10	9.5	0.140	0.243	0.248	0.172	0.519
22	35	17	20	10.2	10	1.0	1.023	8.7	0.143	0.250	0.255	0.159	0.582
23	35	15	23.6	9.66	9.4	1.0	1.1	7.5	0.141	0.242	0.250	0.172	0.572
24	35	17	23.6	9.8	9.6	1.0	1.115	8.0	0.140	0.245	0.250	0.172	0.300
25	17	15	9.6	9.1	8.8	1.0	1.015	7.0	0.089	0.285	0.266	0.087	0.314
		15.5	9.7	9.4		1.0	0.96	7.5	0.099	0.285	0.285	0.093	0.297
				10.7			0.98	7.0	0.107	0.280	0.285	0.086	0.316
				10.8				8.0	0.108	0.232	0.275	0.095	0.267
				9.8				10.5	0.1138	0.227	0.252	0.088	0.244
										0.250	0.255	0.076	0.217
									0.141	0.250	0.265	0.078	0.247
									0.	0.260	0.265	0.076	

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Table 3.

Absorption of Ammonia by Water

Number of experiment	Gas phase				Water					Coefficient of absorption
	Temperature °C	Total gas volume liters/min	Partial pressure, mm Hg		Temperature °C	Volume liters/min	Conc'n at outlet grams/liter	Quantity of absorbed NH_3		kg/m^2 $\cdot$ hrs. mm Hg
			at inlet	at outlet				Determined from gas grams/min	Determined from water grams/min	
1	17.5	19.9	73	13.5	13	0.483	2.25	1.09	1.3	0.023
2	16	9.9	48.5	3.5	9	0.497	0.86	0.411	0.427	0.019
3	17	10.1	81.5	6	12	0.5	1.31	0.703	0.655	0.015
4	16.5	10.3	75	7.5	11	0.5	1.25	0.637	0.625	0.016
5	17	20.1	69	17.5	11.5	0.5	2.2	0.945	1.1	0.022
6	17	20.1	72	15	10	0.49	2.21	1.05	1.08	0.022

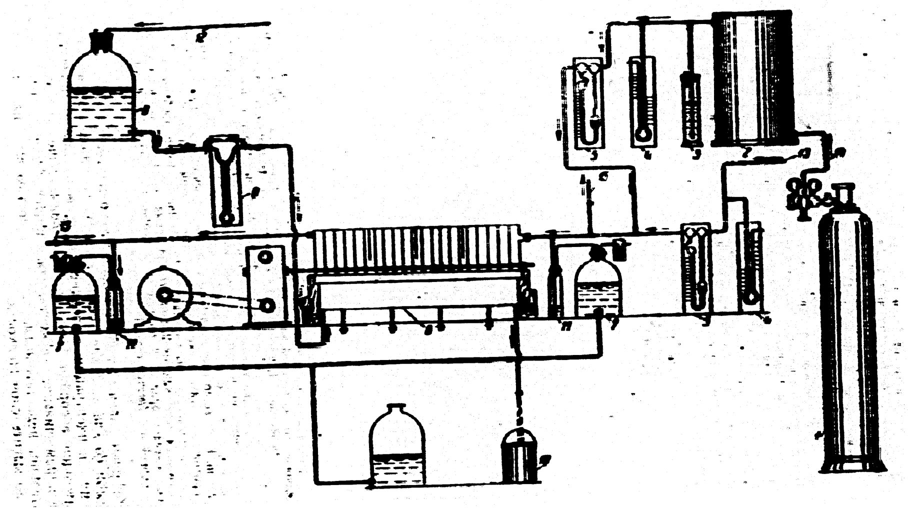

Fig 1. Schematic Drawing of the Experimental Installation with Mechanical Scrubber

1 - Cylinder containing gas to be absorbed; 2- Trap; 3 - Liquid-Filled pressure regulator; 4 - U-shaped pressure gauge; 5 - Flowmeters; 6 - Scrubber 7 - Aspirators; 8 - Pressure vessel; 9 - Flowmeter; 10 - Measuring tank; 11 - Gas trap; 12 - Tap-water line; 13 - Air line from blower; 14 - Gas line; 15 - Exhaust.

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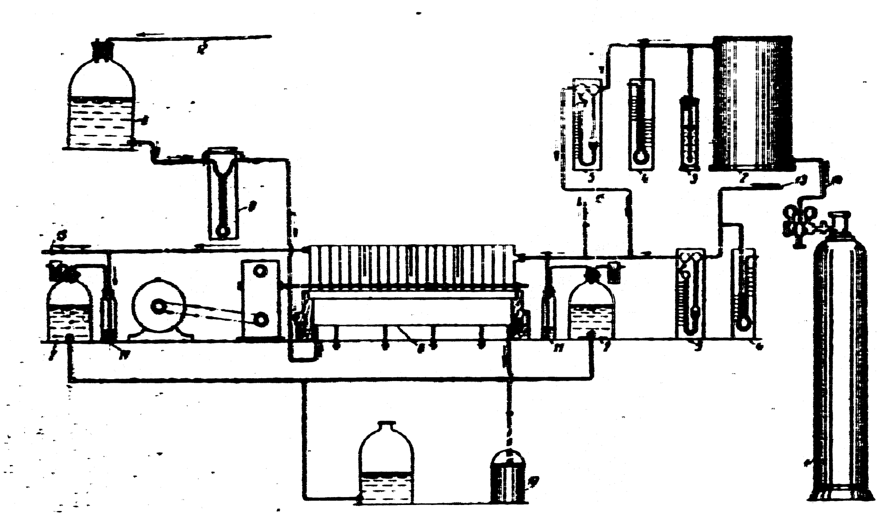

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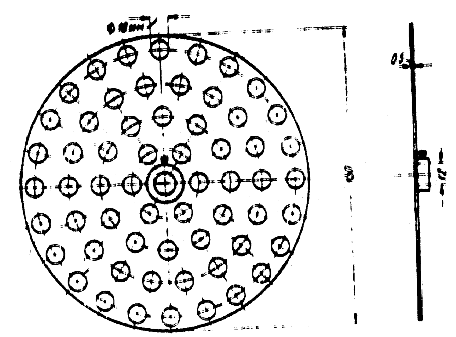

Fig 2. Disk of the Mechanical Scrubber

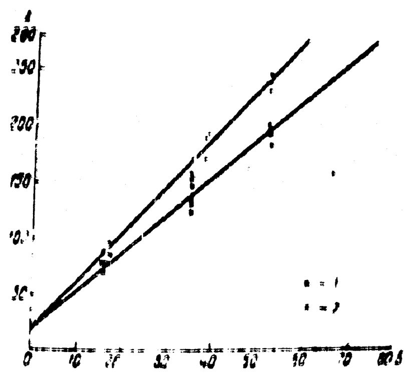

Fig 3. The Dependence of the Coefficient of Absorption of Carbon Dioxide on the rpm of the Disks at Different Rates of Flow of Water

Abscissa: Coefficient of Absorption $K_L \cdot 10^3$; Ordinate: rpm of Disks. Rate of Flow of Water: 1- 0.[illegible] liters/minute; 2- 1.[illegible] liters/minute

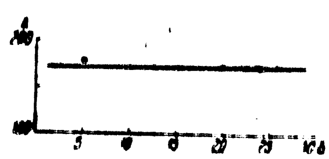

Fig 4. Dependence of the Coefficient of Absorption of Gas on the Rate of Flow of the Gas, at a Rate of Flow of Water of 1 liter/minute and 35 rpm of the Disks.

Abscissa: Coefficient of Absorption of Carbon Dioxide $K_L \cdot 10^3$; Ordinate: Rate of Flow of Gas in liters/minute.

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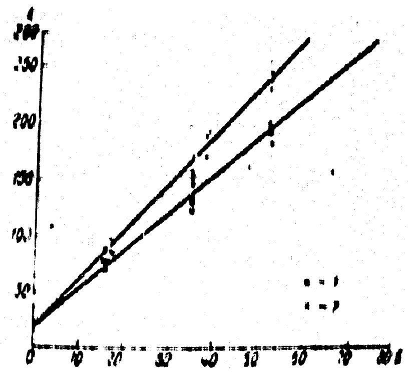
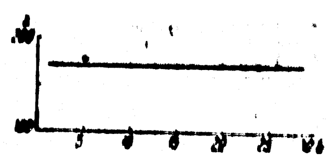


Fig 3. The Dependence of the Coefficient of Absorption of Carbon Dioxide on the rpm of the Disks at Different Rates of Flow of Water

Abscissa: Coefficient of Absorption $K_L \cdot 10^3$ · Ordinate: rpm of Disks. Rate of Flow of Water: 1- 0.5 liters/minute; 2- 1.0 liters/minute



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